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UNITED STATES ARMY
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PREFACE

This report was prepared by Austin Kovacs, Research Civil Engineer, of the Applied Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. The field work was performed by the author and Thomas Fenwick. Funding for this work was provided by the National Science Foundation under interagency agreement DPP77-19565.

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INTRODUCTION

In November of 1978, during radio-echo sounding investigations in the McMurdo Sound area of Antarctica, John Annexstad of NASA asked if we would obtain, with the CRREL 275-MHz impulse radar profiling system, measurements of ice thickness along a leg of a strain net he and members of the Japanese National Institute of Polar Research had installed across the blue ice surface extending westward from the Allan Nunatak. Allan Nunatak is located in the Allan Hills of Victoria Land about 210 km northwest of McMurdo Station on Ross Island.

The interest in the blue ice area west of Allan Nunatak is due to the large concentration of meteorites found on the ice surface by U.S. and Japanese scientists (Anon. 1979). During the winter seasons of 1976-77 and 1977-78, over 500 meteorites and meteorite fragments were found in the area of the Allan Hills (Fig. 1). This collection is of major proportions, as meteorite discoveries in the past have generally been singular finds, numbering a few per decade.

A reason for the large concentration of meteorites on the blue ice in the Allan Hills has been proposed by Dr. W.A. Cassidy (1978), the principal investigator heading up the U.S. team of scientists engaged in Antarctic meteorite studies. He states: "The specimens were found for the most part on the upper and lower limbs of an ice monocline, which may reflect the existence of a near-surface ridge across which the ice is flowing. A very slight consequent elevation of the ice surface over the ridge crest results in greatly increased ablation rates by katabatic winds, leading to constant exposure of older ice at the ablation surface. Meteorites [which have been incorporated into the ice far upstream and gradually transported to this area] are periodically exposed by this process and carried over the monocline to be deposited on the lower limb. Ice in the lower limb is in a stagnant-flow condition because of the barrier presented by the Allan Hills. These relationships are suggested in Figure 2." The above concentration mechanism is based on the existence of a subsurface barrier and high katabatic winds which strip and ablate the top layers of snow and ice flowing into the area and expose meteorites carried by the ice stream. Indeed, only the latter mechanism needs to exist.

To gain insight into the rate and direction of ice flow and the rate of ice ablation, a 13-km-long strain and ablation station array was installed westward from Allan Nunatak by U.S. and Japanese scientists in November 1978. The location and configuration of this array are shown in Figure 3. The elevation of the ice surface from stations 2 to 20 is shown in Figure 4. In this figure the conceptualized bedrock topography is shown as a dotted line. The radio-echo sounder was needed to determine the true bedrock relief along this leg of the strain net.

My reason for visiting the area was to try to locate a meteorite which was still buried within the ice. It was believed that such a find could be of importance in that an independent method for dating the Earth residence time of the meteorite would then be possible. That is, the ice surrounding the meteorite could be dated and compared with the date determined from element decay ratio measurements made on the meteorite.

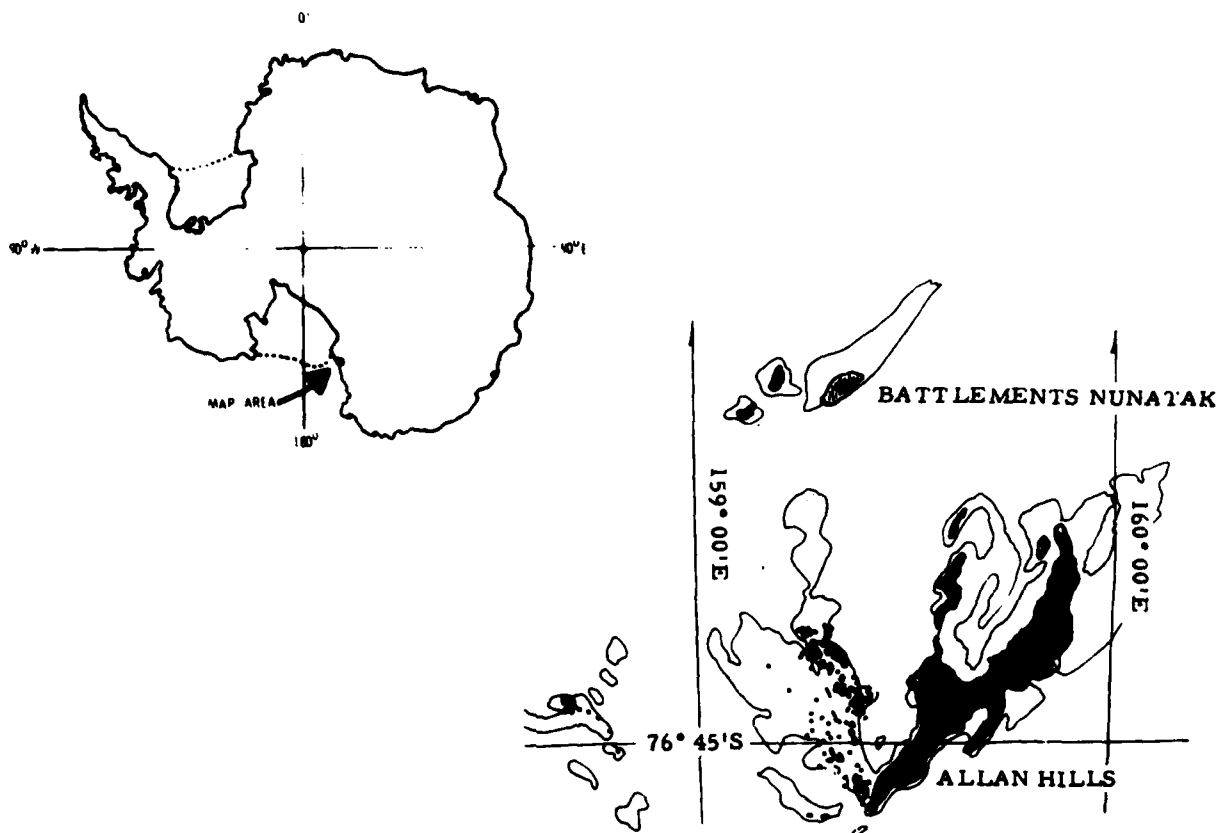


Figure 1. "Field map showing locations of meteorite finds at the Allan Hills site. Rock outcrops are shaded and bare ice patches are outlined. Monocline in the ice surface runs from the southwest end of Allan Hills toward Battlements Nunatak but flattens out before reaching Battlements" (from Cassidy 1978).

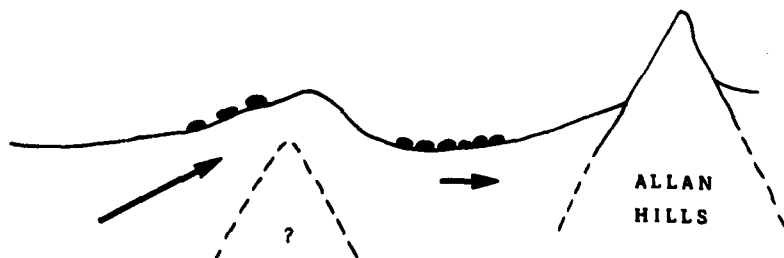


Figure 2. "Sketch of a section crossing the main meteorite site from west to east. (Allan Hills protrudes from the ice to the east, and an inferred ridge lies below the ice surface to the west, causing the ice surface to be monoclinal)" (from Cassidy 1978).

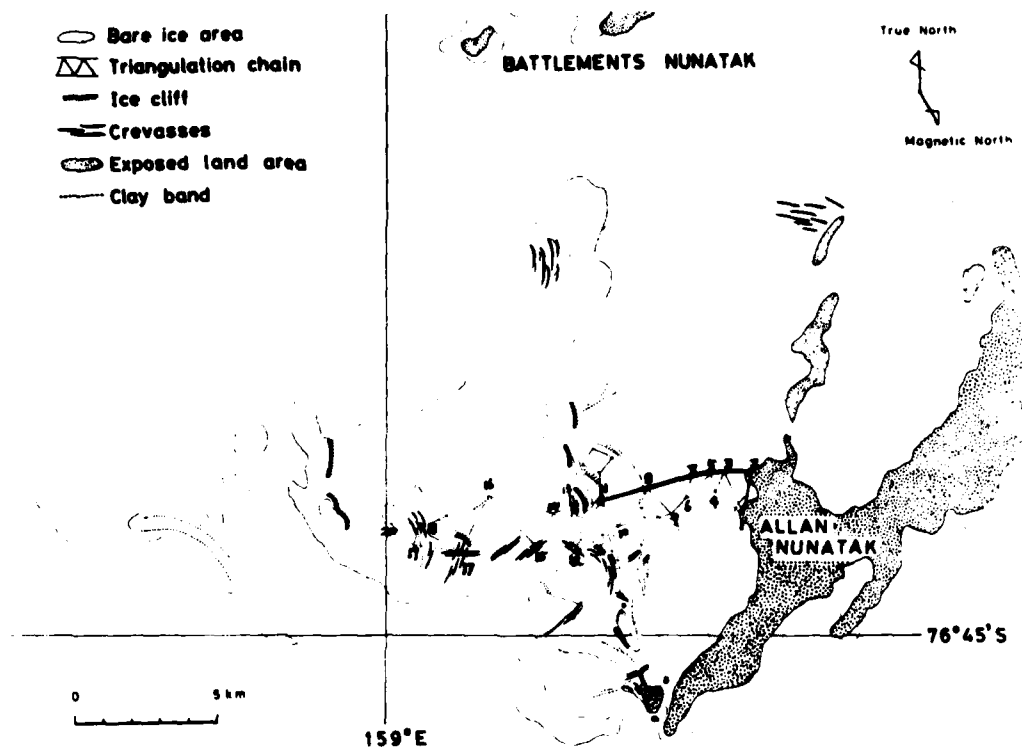


Figure 3. Strain net location map (courtesy of F. Nishio, National Institute of Polar Research, Japan).

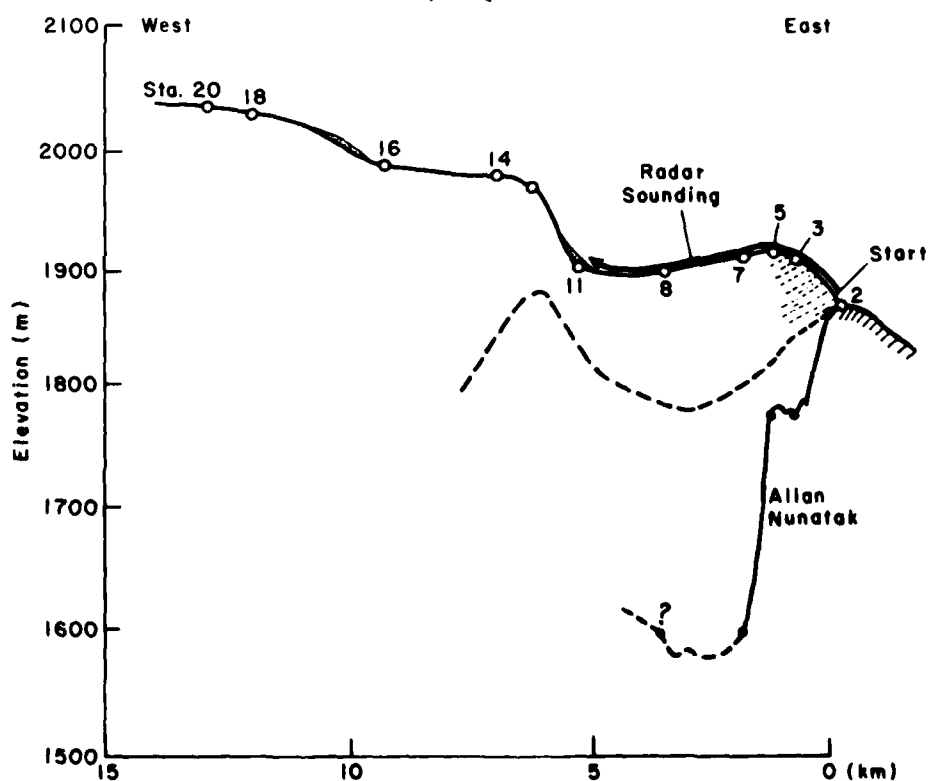


Figure 4. Ice elevations along north leg of strain net (courtesy of F. Nishio) and radio-echo ice thickness sounding results (•).

We agreed to perform the ice thickness survey along the strain net after our own survey work on the McMurdo Ice Shelf and on the Koettlitz Glacier was completed (Gow and Kovacs, in press).

FIELD RESULTS

Ross Island

The possibility of detecting a shallowly buried meteorite, should the radar antenna happen to be pulled over one, was considered to be very high. For example, on the floating Koettlitz Glacier ice tongue we frequently detected accumulations of sand and gravel at the bottom of refrozen cryoconite holes up to 1-1/2 m deep. More important, we believe we detected a large concentration of buried rock in the ice of The Gap between Arrival Heights and Crater Hill. The rock concentration occurred at the snow/ice transition near the top of The Gap. Apparently the rocks were transported to this ablation area in a fashion similar to that proposed by Cassidy. Evidence that the buried targets were rock can be inferred from the pieces of rock seen resting on the ice surface farther downslope. A portion of the graphic record taken across the snowfield from Castle Rock and down the exposed ice of The Gap is shown in Figure 5. The location and nature of the reflected signal from the buried rock are shown in this record, as are dotted lines drawn over internal layers which reveal that the ice is flowing out to the face of the sloping ($\sim 25^\circ$) ice surface.

Allan Nunatak

At the end of our field work on the McMurdo Ice Shelf, the antennas used for making our radio-echo sounding measurements were experiencing severe noise problems which, after we returned to the U.S., were found to be related to poor fabrication and electrical component problems. Therefore, the sounding system was not operating satisfactorily in early December when the scheduled trip to the Allan Hills was planned. Nevertheless, the field trip was undertaken anyway, with limited success.

The day of the survey was sunny but quite uncomfortable because of the high wind and low temperature common to the area. Radio-echo sounding started on the wind-cupped ice surface about 300 m from station 2. About halfway from the start to station 3, the time window had to be doubled because the depth to the ice/bedrock interface was increasing rapidly (Fig. 6). At the same time, antenna noise began to obscure the reflected wavelet from the ice/bedrock interface. This noise became progressively worse on the run from stations 3 to 5 (Fig. 7), and by the time station 8 was reached we could not be sure that what appeared to be ice bottom was indeed the ice/rock interface.

From the two-way time of flight information obtained from the graphic record profile, the ice thickness D at the start of the profile and at stations 2, 3, 5 and 7 was determined to be 11, 130, 128 and 310 m respectively from

$$D = V \frac{t}{2} \quad (1)$$

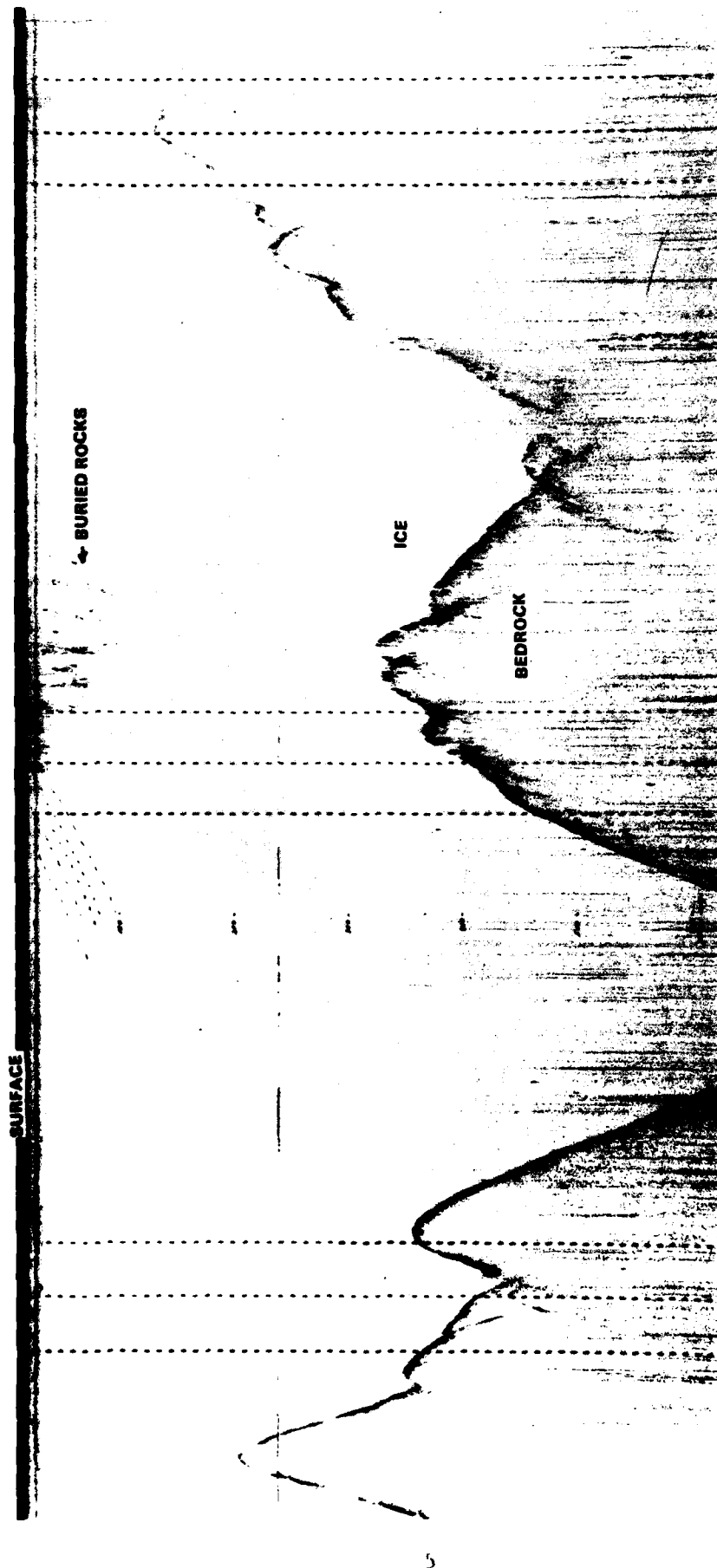


Figure 5. Radio-echo sounding profile beginning about 1 km from Castle Rock on the left and extending to the bottom of The Gap on the right. Distance between vertical dashed lines is 75 m. The area of many internal hyperbolic reflections, a common radar signature of buried targets, is the location of the "buried rocks." The two-way radar signal travel time scale in 100-ns increments is also shown. Time zero is at top of record.

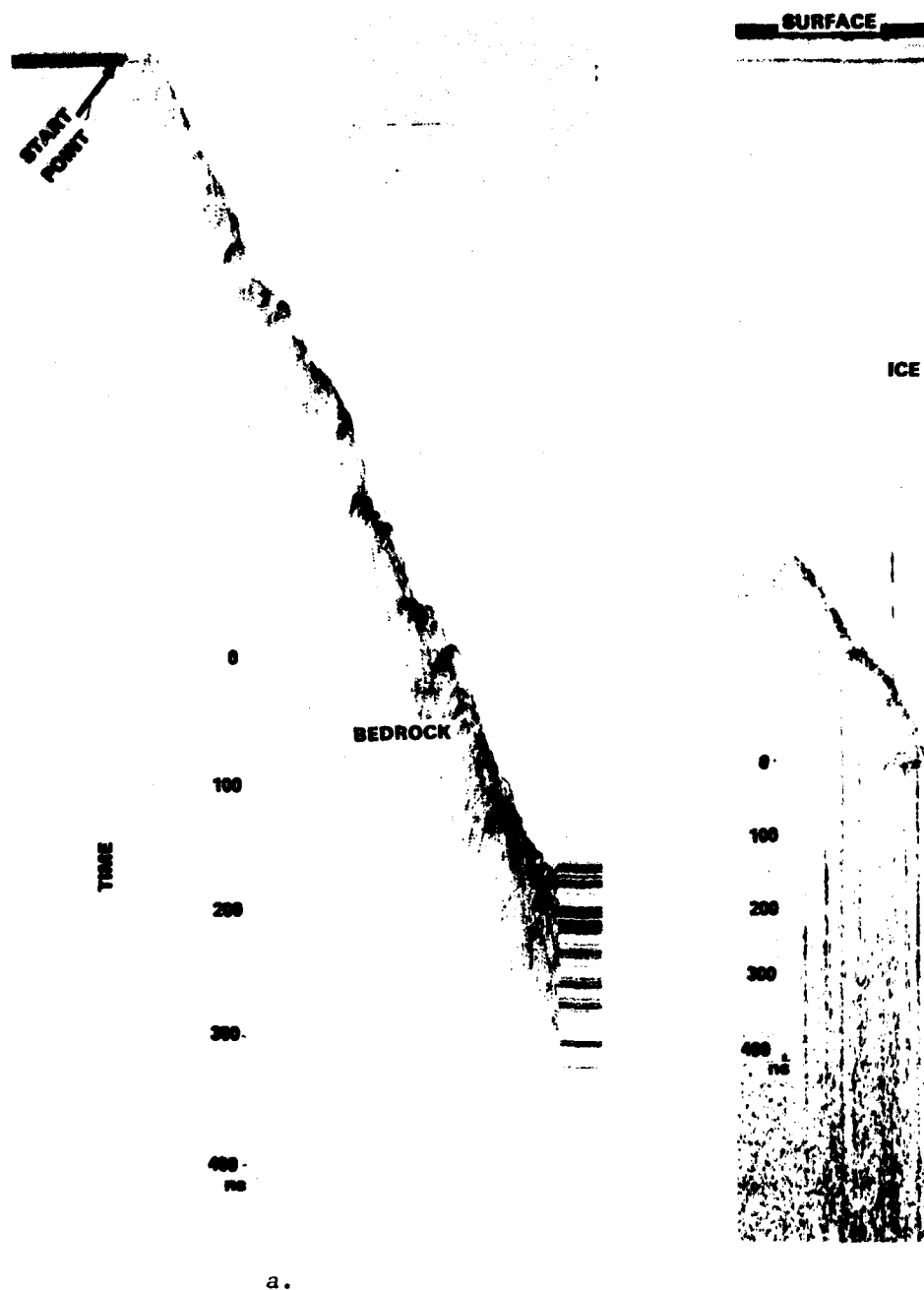


Figure 6. Ice/bedrock interface profile from traverse start (see Fig. 4) to station 3. Time scale in 100-ns increments is shown. Time zero, i.e. ice surface, is 130 ns above rock surface at start point in record a and at top of black band in record b.

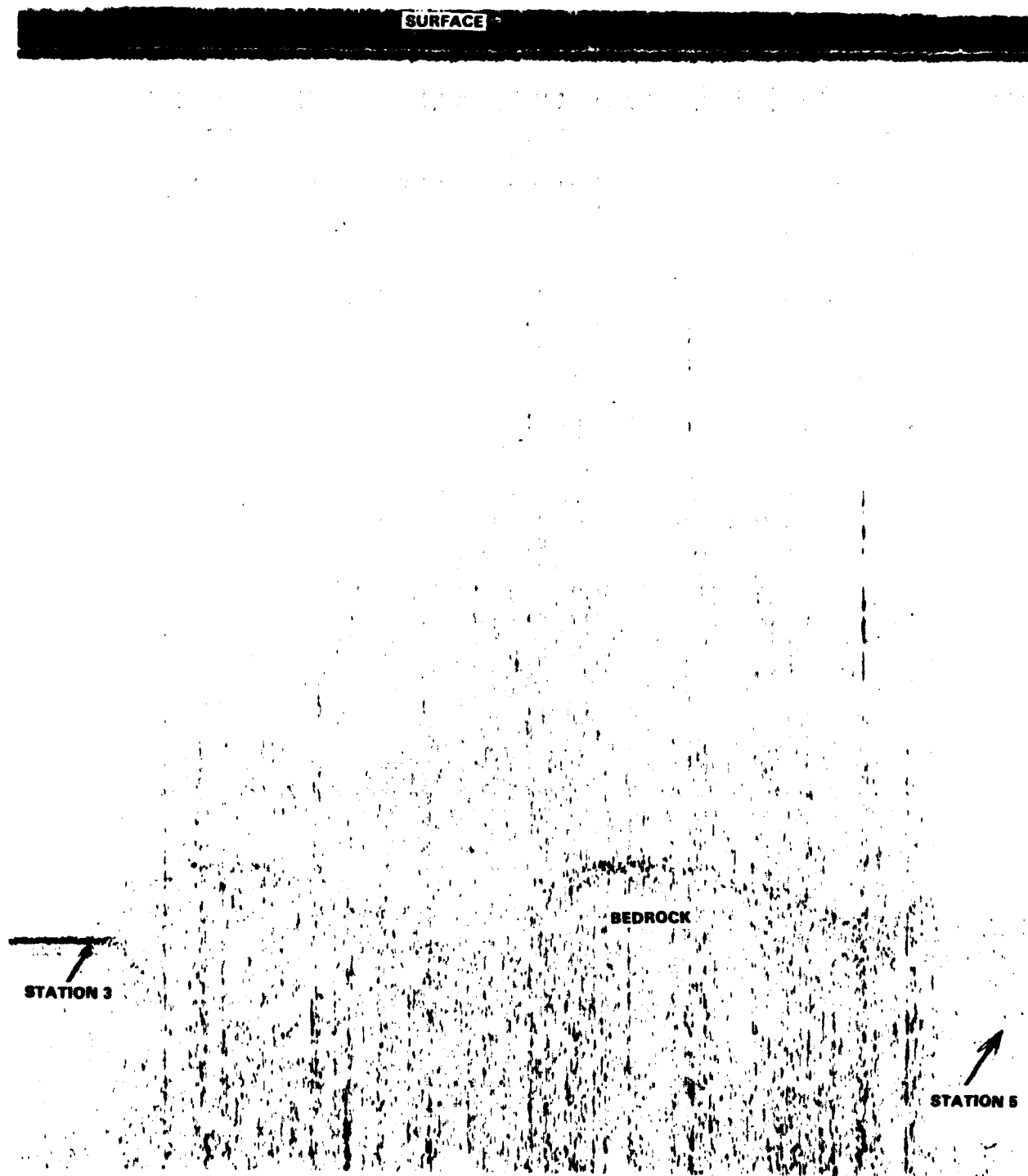


Figure 7. Ice thickness radio-echo profile between stations 3 and 5.

where

V = velocity of electromagnetic wavelet in ice, ~ 0.17 m/ns
 t = two-way flight time obtained from the graphic record.

The apparent interface seen running through the noise on the graphic record at station 8 was at a depth of ~ 300 m.

The above depths are also plotted in Figure 4 and show that Allan Nunatak acts as a "steep"-faced barrier, restricting ice movement to the east. Unfortunately, the existence of a subsurface barrier under the area of the ice monocline, as conceptualized by Cassidy, could not be verified by our limited survey data. In addition, because of system noise problems we did not explore for buried meteorites.

A snow-filled depression in the ice about 100 m wide at the base of the monocline near station 11 was found to be approximately 8 m deep. Internal layering within the snow is clearly in evidence (Fig. 8).

DISCUSSION

High resolution radio-echo profiling would appear to offer the unique possibility of detecting a buried meteorite in glacial ice. The logical place to undertake such a search would be in the area of Allan Nunatak, where many hundreds of meteorites have been found resting on the glacial ice surface in recent years.

High resolution radio-echo sounding measurements west of Allan Nunatak revealed that this formation has a relatively steep face blocking the eastward movement of ice further inland. The greatest ice depth measured was 310 m. While this is the thickest ice measured to date with the CRREL radio-echo sounder, we believe the system's maximum ice profiling depth is greater and that the limitations experienced in this field survey were due to equipment malfunction.

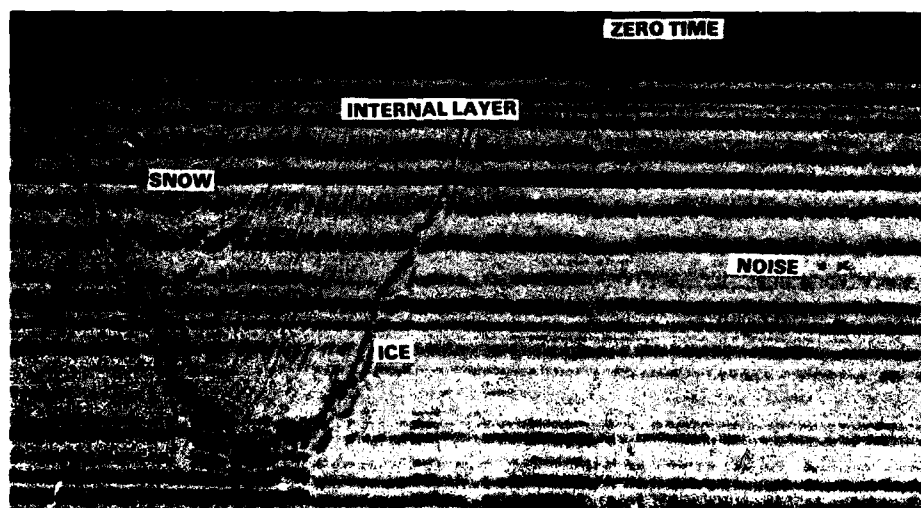


Figure 8. Snow-filled depression in ice near station 11.

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